Journal of Integrated Earth Sciences, 2025, Vol.1(1), December 2025, pp. 72-82
https://doi.org/10.5281/zenodo.18594158 OPEN ACCESS

JOURNAL OF INTEGRATED EARTH SCIENCES

Entropy-weighted Irrigation Water Quality Index (EIWQI) for the Analysis of Irrigation Water Quality of Kerala, India

Raicy M C[a], Mohammed Maharoof P[a], Olivia Maria[b], C D Aju[c], A. L Achu[d]

[a] Hydrology and Climatology Research Group, Centre for Water Resources Development and Management (CWRDM), Kunnamangalam, Kozhikode-673 570, Kerala, India

[b] School of Earth Sciences, Central University of Karnataka, Kalaburagi, Karnataka, India

[c] Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Pune, India

[d] Department of Climate Variability and Aquatic Ecosystems, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, Kerala, India

ARTICLE INFO

Received. 05 January 2025
Revised. 28 February 2025
Accepted. 05 March 2025

KEYWORDS
Irrigational Water Quality;
Hydrochemistry; Kerala;
Entropy weighted Irrigation Water Quality Index

How to cite
Raicy Mani, C., Mohammed Maharoof P, Olivia Maria, C D Aju, & A. L Achu. (2026). Entropy-weighted Irrigation Water Quality Index (EIWQI) for the Analysis of Irrigation Water Quality of Kerala, India. Journal of Integrated Earth Sciences, 1(1), 72–82. https://doi.org/10.5281/zenodo.18594158

ABSTRACT

Irrigation water quality assessment is critical in ensuring optimal crop productivity, maintaining soil health, protecting the ecosystems, and promoting sustainable agricultural practices. This study assesses the irrigation water quality of groundwater in Kerala State, South India using various irrigational water quality indices such as Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Percentage of Sodium (Na%), Permeability Index (PI), Magnesium Adsorption Ratio (MAR), and Entropy Weighted Irrigation Water Quality Index (EIWQI). For this purpose, the hydrochemical data of 620 observation wells for a period of 5 years from 2018 to 2022 were procured from the Central Groundwater Board, Government of India and the spatiotemporal variations in various irrigation water quality indices were analysed in GIS platform. SAR of groundwater samples varied from 0.2 to 11 indicating varying levels of sodium hazard, while RSC ranged from -7 to 2.2 and Na% ranged from 14 to 84. The PI values ranged from 20 to 200, and MAR values ranged from 5.3 to 98. The EIWQI zonation indicates that the irrigation water quality varies not only based on the physiography of the state, but also on the northern and southern parts of the state. The study concluded that most of the parameters indicate that the highland areas particularly towards the central Kerala is more affected for irrigational groundwater quality when compared to the midland and lowland areas. Most water samples fall into a category that requires careful management to avoid further deterioration. This study implies the importance of regular monitoring and comprehensive analysis of irrigation water quality to ensure sustainable agricultural practices and long-term soil fertility in the state.

CONTACT Author, Raicy M C - raicygeo@gmail.com
Supplemental data for this article can be accessed online at our website

1. Introduction

Water is vital for life and the earth's functions, playing a crucial role in the sustainable development of nations through its availability as a natural resource. The increasing demand for water causes groundwater depletion, especially in arid and semiarid regions (Siebert et al. 2010), impacting the overall groundwater sustainability (Houemenou et al. 2020; Azzirgue et al. 2022; Docheshmeh Gorgij et al. 2023). In areas where groundwater is the primary source for agriculture, these impacts are so crucial. For example, over-extraction of groundwater for agriculture has been reported to have significant economic and environmental impacts in countries like Bangladesh, Iran, India, and Sri Lanka with reduced farm income, declining water tables, and substantial environmental damage Adopting effective management strategies is critical to aligning agricultural productivity with groundwater preservation.

Evidence suggests that nearly 60% of groundwater abstraction in developing regions is used for irrigation (Aliyu et al., 2017; Velasco-Muñoz et al., 2018). The effectiveness of irrigation, however, is closely linked to the chemical properties of the water, particularly salinity levels and concentrations of dissolved salts (Zaman et al., 2018; Malakar et al., 2019; Mirzavand et al., 2020). These factors influence soil fertility, crop health, and the operational efficiency of irrigation systems (Adimalla, 2018; Ramadan et al., 2019). As a result, systematic evaluation of irrigation water quality becomes essential for maintaining soil productivity and maximizing crop yields (Chowdury et al., 2019; Zhu et al., 2019; Rahman et al., 2020; Chidambaram et al., 2022).

Various methodologies have been developed to assess irrigation water suitability, many of which utilize hydrochemical indices to establish baseline concentrations and interpret groundwater quality (Edmunds et al., 2003; Li et al., 2013; Das et al., 2020). For instance, Zafar et al. (2024) applied conventional techniques such as the Irrigation Coefficient, Sodium Adsorption Ratio (SAR), Total Alkalinity, and Total Dissolved Solids (TDS), refining their analysis using an ideal solution model as a benchmark. Contemporary evaluation frameworks often integrate index-based, statistical, and geospatial tools to provide both analytical depth and spatial visualization of groundwater quality trends (Das et al., 2020; El Mountassir et al., 2020; Gao et al., 2020; Jahin et al., 2020; Wu et al., 2020; Chidambaram et al., 2022; Docheshmeh Gorgij et al., 2023).

The Irrigation Water Quality Index (IWQI), introduced by Meireles et al. (2010), is a specialized extension of the broader Water Quality Index (WQI) and is tailored specifically for irrigation assessment. It incorporates international water quality guidelines, including those proposed by Ayers and Westcot (1985). Over time, this framework has evolved to reduce subjectivity and enhance interpretability. For example, Simsek and Gunduz (2007) applied the IWQI to Turkey's Simav Plain, classifying irrigation suitability into discrete quality categories. Singh et al. (2018) further improved the index by integrating the Analytic Hierarchy Process (AHP) proposed by Saaty, enhancing its decision-making capacity. Recent developments have focused on combining IWQI with Geographic Information Systems (GIS) to spatially map water quality, as demonstrated by researchers such as Batarseh et al. (2021), Çadraku (2021), Passos et al. (2019), Akter et al. (2016), and Al-Hadithi et al. (2019).

In parallel, artificial intelligence methods have gained traction in optimizing WQI computations. Studies by Docheshmeh Gorgij et al. (2023), Chidambaram et al. (2022), Valentini et al. (2021), Bui et al. (2020), and Ahmed et al. (2019) have applied machine learning algorithms to improve prediction accuracy and streamline water quality evaluation. Several water chemistry parameters including major cations/anions, electrical conductivity, SAR, and related indices are routinely incorporated into these models to calculate IWQI. However, existing approaches often fall short of integrating all relevant variables into a single, unified framework. To address this gap, the present study employs the Entropy-Weighted Irrigation Water Quality Index (EIWQI) to assess irrigation suitability across Kerala, a tropical state in southwestern India. The EIWQI method incorporates entropy theory to objectively assign weights to individual water quality parameters, drawing from methodologies described by Li et al. (2010), Amiri et al. (2014), and Docheshmeh Gorgij et al. (2019). By applying this comprehensive index, the study aims to provide a more robust and spatially informed assessment of irrigation water quality in the region.

2. Study Area

Kerala State, located on the southwestern coast of India, is a narrow strip of land covering an area of 38,863 km². The state is bounded by the Lakshadweep Sea to the west and the states of Tamil Nadu and Karnataka to the east. Stretching about 560 km from north to south, Kerala has an average width of 70 km and a maximum width of 125 km (Figure 1). Geographically, it lies between latitudes 8°17′30″ N and 12°47′40″ N and longitudes 74°27′47″ E and 77°37′12″ E. Physiographically, Kerala can be divided into four distinct regions running parallel to its coastline: the Western Ghats, the foothills, the midlands, and the coastal lowlands. The state is drained by 44 rivers, most of which originate in the Western Ghats. Among these, the Kabini, Bhavani, and Pambar Rivers flow eastward into neighboring states, while the majority flow westward, discharging into the Arabian Sea or feeding into an extensive network of backwaters. Geologically, Kerala forms part of the Indian Craton, bounded by the Western Ghats to the east and the Arabian Sea to the west. The rock formations are primarily classified into Precambrian crystalline rocks, Tertiary sediments, and Quaternary deposits, reflecting the complex geological history of Kerala.

https://doi.org/10.5281/zenodo.18594158

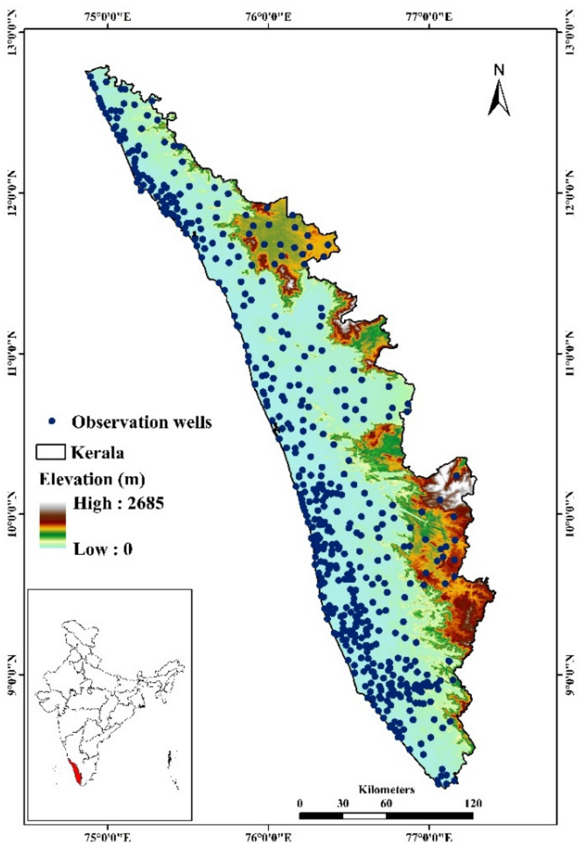

Figure 1: Geographical location of the study area with observation wells

3. Materials and methods

As part of this investigation, hydrochemical data from 620 groundwater wells, spanning the years 2018 to 2022, were obtained from the Central Groundwater Board (CGWB), Government of India. To ensure the reliability of the chemical analyses, the Error in Ionic Balance (EIB) was calculated (Equation 1), comparing the total concentrations of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, F^{-}), with all values expressed in milliequivalents per litre (meq/L). In the current study area, the EIB values were found to fall within the acceptable threshold of ±5%, consistent with the standard recommended by Domenico and Schwartz (1990).

$$EIB = \frac{TCC - TCA}{TCC + TCA} \times 100 \qquad (1)$$

3.1 Irrigation water quality indices

In India, irrigation systems play major roles in crop productivity which mainly rely on groundwater (Mukherji, 2007). The quality of groundwater highlights the mineral composition, which in turn influences soil and plant health (Adimalla et al., 2020).

In this investigation, our emphasis lies on the quantification of parameters such as total hardness (TH), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Permeability Index (PI), Magnesium Adsorption Ratio (MAR), and Na^{+} percentage (Na%) through the following determinations. Further, the average indices for five years have been used to estimate the EIWQI for Kerala State.

3.2 Total hardness (TH)

Residual Sodium Carbonate (RSC) is used to evaluate the potential of irrigation water to precipitate calcium and magnesium in soils. When the combined concentrations of bicarbonate (HCO_3^{-}) and carbonate (CO_3^{2-}) exceed those of Ca^{2+} and Mg^{2+}, precipitation can occur, reducing the availability of these essential nutrients in the soil. The RSC index, introduced by Richards (1954), is calculated as (Equation 2):

$$TH = \sum sum\ of\ multivalent\ cations = Ca^{2+} + Mg^{2+} \qquad (2)$$

3.3 Residual sodium carbonate (RSC)

When the summation of HCO_3^{-} and CO_3^{2-} concentration exceeds the Ca^{2+} and Mg^{2+} concentrations, Ca^{2+} and Mg^{2+} will precipitate in the soil. Richards (1954) calculated the RSC index which can be expressed below (Equation 3):

$$RSC = \left(HCO_3^{\ -} + CO_3^{\ -2}\right) - \left(Ca^{2+} + Mg^{2+}\right) \qquad (3)$$

3.4 Sodium percentage (Na%)

The suitability of irrigation water is determined by the concentration of sodium or the soluble sodium percentage (SSP) (Haritash et al., 2008; Khan et al., 2021). The index value plays a crucial role in assessing the water's appropriateness for irrigation (Shammi et al., 2016).
Elevated concentrations of soluble sodium in irrigation water can pose salinity hazards, especially in the presence of accompanying anions such as sulfate (SO_4^{2-}) and chloride (Cl^{-}), which may adversely affect soil permeability and crop productivity (Sarkar et al., 2021). The Soluble Sodium Percentage (SSP), a key parameter for assessing sodium-related hazards, is computed using the equation proposed by Todd and Mays (2004), as given below (Equation 4):

$$Na\% = \frac{(Na^{2+} + K^{+})}{(Ca^{2+} + Mg^{2+} + Na^{2+} + K^{+})} \times 100 \qquad (4)$$

3.5 Sodium adsorption ratio (SAR)

The interaction between sodium (Na^{+}), calcium (Ca^{2+}), and magnesium (Mg^{2+}) in irrigation water is quantified through the Sodium Adsorption Ratio (SAR), an important index used to evaluate the potential sodium hazard to soil and crops (Alrajhi et al., 2015; Sarkar et al., 2021). SAR is critical in determining the extent to which sodium can affect soil structure, as excessive sodium can displace calcium and magnesium on soil particles, leading to reduced permeability and aeration (Mukhopadhyay et al., 2022). Consequently, SAR serves as a key indicator in assessing the suitability of water for irrigation use.The impact of SAR is closely associated with the salinity status of the water, often measured through electrical conductivity (EC). High SAR values, especially in combination with elevated EC, can impair crop growth and soil health. According to international standards, including those from the World Health Organization (WHO, 2011) and the Food and Agriculture Organization (FAO, 2017), irrigation water with a SAR value greater than 10 is generally considered unsuitable for agricultural use. In this study, SAR values were computed using the standard equation proposed by Richards (1954), as shown below (Equation 5):

$$SAR = \frac{Na^{2+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \qquad (5)$$

3.6 Permeability index (PI)

Soil permeability in irrigated regions is largely influenced by the ionic composition of the applied water, particularly its salt concentration (Safiur Rahman et al., 2017). To evaluate this, the Permeability Index (PI) was introduced by Doneen (1964) as a diagnostic tool for assessing irrigation water quality. Among the key influencing constituents, calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium, particularly in the form of sodium chloride, have a direct impact on the infiltration and permeability characteristics of soils (El Maghraby and Bamousa, 2021). The PI is computed using the following expression (Equation 6):

$$PI = \frac{\left(Na^{2+} + \sqrt{HCO_3^{-}}\right) \times 100}{(Ca^{2+} + Mg^{2+} + Na^{2+})} \qquad (6)$$

3.7 Magnesium adsorption ratio

Calcium (Ca^{2+}) and magnesium (Mg^{2+}) typically maintain a natural balance in most groundwater systems. However, elevated levels of Mg^{2+} can disrupt this equilibrium, potentially leading to increased alkalinity in irrigation water, which may adversely affect plant growth. The Magnesium Ratio (MR), an important indicator of such imbalance, is calculated using the formula provided by Abdulhssain (2018) (Equation 7):

$$MAR = \frac{Mg^{2+}}{Mg^{2+} + Ca^{2+}} \times 100 \qquad (7)$$

3.8 Entropy weighted Irrigation Water Quality Index

Entropy is a statistical concept used to quantify the degree of uncertainty or disorder within a dataset, and it is widely applied to assess variability in environmental systems (Guey-Shin et al., 2011). In the Entropy-based Irrigation Water Quality Index (EIWQI) framework, the computation proceeds through a series of defined stages. The process begins with the construction of a matrix, commonly referred to as the eigenvalue matrix '*X*', which encompasses irrigation water quality data for '*m*' samples across '*n*' parameters. The specific formulation of this matrix is elaborated upon in the subsequent formula (Equation 8):

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots x_{1n} \\ x_{21} & x_{22} & \dots x_{2n} \\ x_{m1} & x_{m2} & \dots x_{mn} \end{bmatrix} \qquad (8)$$

The units of irrigation water quality parameters are normalized, to minimize the errors, and the normalized matrix is represented as follows.

$$y_{ij} = \frac{x_{ij} - (x_{ij})_{min}}{(x_{ij})_{max} - (x_{ij})_{min}} \qquad (9)$$

The value of each parameter (Pj) is estimated using the following relation Equation 10.

$$P_{ij} = \frac{(y_{ij})}{\sum_{i=1}^{m}(y_{ij})} \qquad (10)$$

Further, the information entropy (ej) and the entropy weight (w_j) are estimated using the following Equations 11 & 12.

$$e_j = -\frac{1}{Inm}\sum_{i=1}^{m} P_{ij} In P_{ij} \qquad (11)$$

$$w_j = \frac{(1 - e_j)}{\sum_{i=1}^{m}(1 - e_j)} \qquad (12)$$

The quality rating scale 'q_j' of parameter 'j' is

evaluated using Equation 13, which is represented as follows.

$$q_j = \left\{\frac{C_j}{S_j} \times 100\right. \qquad (13)$$

Finally, EWQI is calculated by using (Equation 14).

$$EWQI = \sum_{j=1}^{m} w_j q_j \quad (14)$$

Further, the spatial maps of all the indices were plotted using the Inverse Distance Weighting (IDW) tool of ArcGIS software to understand the spatial variations in the state.

4. Results and Discussion

The average irrigation water quality indices and EIWQI, estimated for Kerala State, and the respective percentage of samples corresponding to highlands, midlands, and lowlands are shown in Table 1. The table provides a classification of groundwater quality based on these indices, each of which is evaluated according to specific standard ranges. The details of each index are discussed in the following subheads.

4.1 Permeability index (PI)

The PI in Kerala ranges from 9.597 to 214.68, with an average value of 91.59. According to Doneen classification (1964), PI values are classified into class I, class II, and class III, with PI>75%, (appropriate), 25%<PI<75% (good), and PI<25% (unsuitable), which is also applied widely in similar studies (Rawat 2018; Amrani 2022). Based on this, in the highland and midland regions, 75.54% and 80.15% of the samples fall under the 'excellent' category, respectively, while 24.46% and 19.85% of samples fall under 'good' category. In contrast, in the lowland areas, 54.67% of samples fall under the 'excellent' category, 44.86% under the 'good' category, and 0.47% under the 'unsuitable' category as detailed in Table 1. Samples falling under classes I and II ensure sufficient quality to support healthy crop growth and maintain soil conditions and are recommended for irrigation. Class I water, with a PI above 75%, is particularly favorable for irrigation, posing a minimal risk of soil degradation or crop yield loss. Class II water, with a PI between 25% and 75%, is generally suitable for irrigation but may require more careful management to prevent potential long-term soil issues. Fig. 2b illustrates the spatial distribution of PI values, showing that the southern midland, highland, and northern highland regions of the state have the highest PI values.

4.2 Residual Sodium Carbonate (RSC)

The RSC in the groundwater samples in Kerala ranges from -4.019 to 0.930, with an average of -0.182. The spatial variation map of RSC values is shown in Fig 2a. All the groundwater samples from the highland, midland, and lowland fall within the 'excellent' water quality category, as illustrated in Table 1, suggesting minimal risk of sodium accumulation which could otherwise affect soil structure and crop health.

Figure 2a highlights consistent excellent categories across diverse physiographic units in the state suggesting that the groundwater in most areas is suitable for irrigation with respect to sodium concentration, making it highly reliable for agricultural purposes. The excellent RSC levels contribute to maintain soil structure and fertility, ensuring sustainable crop production.

4.3 Sodium percentage (Na%)

The sodium percentage in groundwater samples ranges from 11.72 to 88.035, with an average of 46.90. Most of the groundwater samples are suitable for irrigation, contributing 2.88% excellent category in highlands, 1.12% in midlands, and 11.21% in lowlands samples. Similarly, 20.14% of good category samples correspond to highlands, 27.34% to midlands, and 37.38% to lowland areas.' Similarly, 48.20% of samples in the highland 48.31% in the midland, and 35.05% in the lowland corresponds to the permissible category. The doubtful category comprises 27.34% of samples in the highland, 22.85% in the midland, and 16.36% in the lowland, indicating potential risks if used for irrigation for a longer duration. Nearly 1.44% of samples were categorized as unsuitable in the highland, and 0.37% in midland, highlighting localized concerns. The highest Na% values are distributed in the southern highland, midland, and lowland areas (Fig. 2c), with elevated levels in central highland and midland regions, emphasizing the need for careful management in areas where irrigation practices are predominant to mitigate potential adverse effects on soil and crop health. The Na% exceeds the permissible limit in several areas. High salt concentrations in the soil negatively affect aeration, infiltration, and soil composition (Chidambaram, et al, 2014).

4.4 Magnesium Hazard (MH)

Magnesium hazard in the study area varies between 4.584 and 100, with an average of 32.36. Significant majority of samples fall in the 'excellent' category of irrigation water quality, comprising 87.05% in the highland, 86.14% in the midland, and 92.99% in the lowland areas.

This indicates that most groundwater samples in these regions have magnesium levels, favorable for irrigation purposes. Samples falling in the unsuitable category comprise 12.95% of samples in the highland, 13.86% in the midland, and 7.01% in the lowland areas. Spatially, the highest values were detected in the central highland region, followed by the northern midland and highland areas, and the southern midland area, as illustrated in Figure 3a. This spatial distribution highlights specific areas where magnesium levels are particularly high, necessitating careful consideration and management.

Table 1: Various water quality indices with standard categorization and their respective % of samples in highlands, midlands, and lowlands

Indices	Standard classification	Groundwater category	High land	Mid land	Low land
PI	>75	Excellent	75.54%	80.15%	54.67%
	25-75	Good	24.46%	19.85%	44.86%
	<25	Unsuitable	0.00%	0.00%	0.47%
RSC	<1.25	Excellent	100.00%	100.00%	100.00%
	1.25-2.25	Doubtful	0.00%	0.00%	0.00%
	>2.25	Unsuitable	0.00%	0.00%	0.00%
MAR	<50	Excellent	87.05%	86.14%	92.99%
	>50	Unsuitable	12.95%	13.86%	7.01%
Na%	<20	Excellent	2.88%	1.12%	11.21%
	20-40	Good	20.14%	27.34%	37.38%
	40-60	permissible	48.20%	48.31%	35.05%
	60-80	Doubtful	27.34%	22.85%	16.36%
	>80	Unsuitable	1.44%	0.37%	0.00%
SAR	<10	Excellent	100.00%	100.00%	99.53%
	10 to 18	Good	0.00%	0.00%	0.47%
	18-26	Doubtful	0.00%	0.00%	0.00%
	>26	Unsuitable	0.00%	0.00%	0.00%
TH	0-60	soft	71.22%	68.16%	35.51%
	60-120	moderate	16.55%	22.47%	27.57%
	120-180	hard	5.76%	4.87%	21.03%
	>180	very hard	6.47%	4.49%	15.89%
EIWQI	<50	Excellent	1.44%	0.75%	3.27%
	50-100	Good	82.73%	90.64%	80.84%
	100-200	Doubtful	15.83%	8.61%	15.89%
	>200	Unsuitable	0.00%	0.00%	0.00%

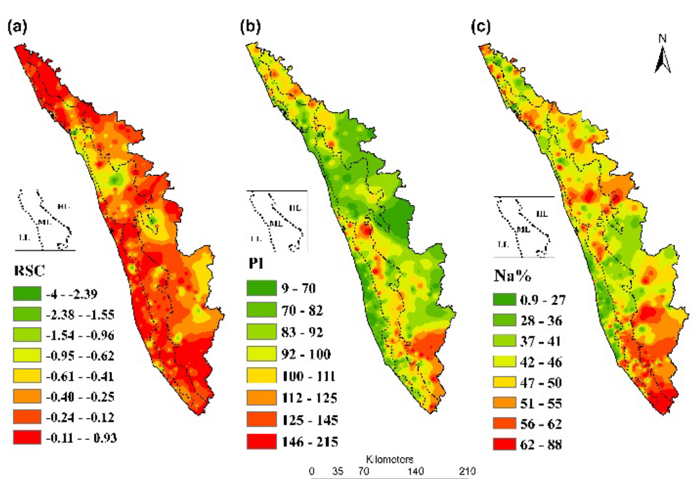

Figure 2: Spatial variation of residual sodium carbonate (a), permeability (b), and sodium percentage (c) Kerala

4.5 Sodium Adsorption Ratio (SAR)

Groundwater suitability for irrigation is also determined by SAR. According to Todd (2004) and Sadashivaiah (2008), SAR values are classified into four categories: ‘excellent’ (<10), ‘good’ (10 <SAR>18), ‘doubtful’ (18 <SAR>26), and ‘unsuitable’ (> 26). In this study, SAR values range from 0.163 to 11.806, with an average of 1.163. In the highland and midland areas, all samples fall under the ‘excellent’ category. In the lowland area, 99.53% of the samples are classified as ‘excellent,’ while 0.47% are categorized as ‘good’ (Table 1). Figure 3b illustrates the spatial distribution of SAR, with the highest concentrations observed in the central midland region with very few samples falling into the ‘good’ category and none in the ‘doubtful’ or ‘unsuitable’ categories, showcasing the suitability of water for irrigation. According to the World Health Organization (WHO, 2011) and the Food and Agriculture Organization (FAO, 2017), SAR values greater than 10 are deemed unsuitable for irrigation purposes. Elevated SAR values increase the risk of sodium salinity, which negatively impacts crop growth by reducing the availability of soil water and altering the balance of essential minerals, such as calcium and magnesium. In this study, only 0.47% of groundwater samples from the lowland area are characterized by SAR values exceeding 10, indicating suitability of majority of water samples for irrigation with respect to SAR levels.

4.6 Total hardness

Total hardness (TH) in groundwater samples ranges from 2 to 480, with an average of 74.99. A significant variation in TH could be noticed across the study area (Figure 3c). In highlands, 71.22% of samples fall under the ‘soft’ category, 16.55% under the ‘moderate’ category, 5.76% under the ‘hard’ category, and 6.47% under the ‘very hard’ category. Similarly, in midlands, 68.16% of samples are classified as ‘soft,’ 22.47% as ‘moderate,’ 4.87% as ‘hard,’ and 4.49% as ‘very hard.’ In the lowlands, the distribution is more diverse, with 35.51% of samples in fall in the ‘soft’ category, 27.57% in the ‘moderate’ category, 21.03% in the ‘hard’ category, and 15.89% in the ‘very hard’ category (Table 1).

4.7 EIWQI (Entropy weighted irrigational water quality index)

The EIWQI values range from -0.584 to 174.169, with an average of 82.63. The classification of EIWQI for different regions shows distinct variations. In the highlands, 1.44% of samples fall under the ‘excellent’ category, 82.73% under the ‘good’ category, and 15.83% under the ‘doubtful’ category.

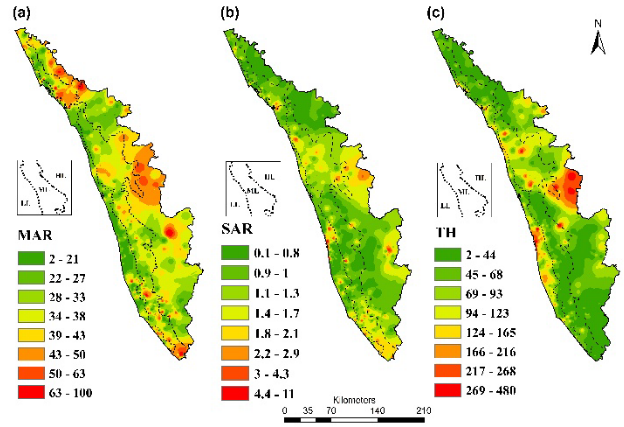

Figure 3: Spatial Variation of Magnesium absorption ratio (a), Sodium Adsorption Ratio (b) total hardness (c) in the study area

4.7 EIWQI (Entropy weighted irrigational water quality index)

The EIWQI values range from -0.584 to 174.169, with an average of 82.63. The classification of EIWQI for different regions show distinct variations. In the highlands, 1.44% of samples fall under the ‘excellent’ category, 82.73% under the ‘good’ category, and 15.83% under the ‘doubtful’ category. In the midlands, 0.75% of samples are classified as ‘excellent,’ 90.64% as ‘good,’ and 8.61% as ‘doubtful.’ In the lowlands, 3.27% of samples fall under the ‘excellent’ category, 80.84% under the ‘good’ category, and 15.89% under the ‘doubtful’ category. Notably, no samples in any of the regions were categorized as ‘unsuitable’ (Table 1).

The spatial distribution of EIWQI, as illustrated in Figure 4, indicates that areas with dominance of the ‘doubtful’ category are primarily located in the central and southern parts of the highland, midland, and lowland regions. This distribution suggests that while the majority of groundwater samples in these regions are of good quality for irrigation, there are specific areas where the water quality is less reliable and falls into the doubtful category. This information is critical for agricultural planning and water resource management in these regions to ensure sustainable irrigation practices.

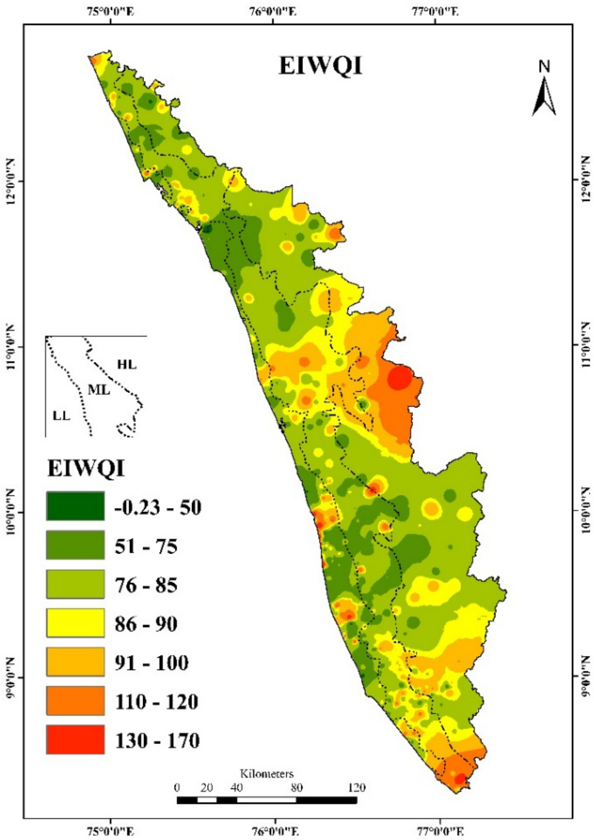

Figure 4: Spatial distribution of Entropy weighted irrigational water quality index (EIWQI)

5. Conclusions

The groundwater quality in Kerala State varies significantly across physiographic divisions, as indicated by various irrigation water quality indices such as PI, RSC, MAR, Na%, SAR, TH, and EIWQI. The majority of the groundwater samples fall within the 'excellent' or 'good' categories, making them suitable for irrigation. Specifically, the permeability index (PI) shows a dominance of 'excellent' water in the highland and midland areas. The Na% of most water samples falls under permissible and doubtful categories, indicating the need for careful management to prevent soil and crop health issues. Similarly, the magnesium hazard of most samples is in the 'excellent' category. The SAR predominantly falls within the 'excellent' category, while some samples in the lowland areas fall under the 'good' category. The TH varies spatially, with soft water dominating in the highland and midland areas and hard and very hard water, dominating in the low land areas. The EIWQI further supports the finding that most groundwater samples are suitable for irrigation, although specific areas in the central and southern regions exhibit doubtful quality. This comprehensive analysis underscores the importance of continuous monitoring and managing groundwater resources to maintain soil health and ensure sustainable agricultural productivity in Kerala State.

CRediT authorship contribution statement.

Raicy M C: Writing – original draft, Supervision, Conceptualization. **Mohammed Maharoof P:** Writing – review & editing, Formal analysis, Data curation, Software, Field Work. **Olivia Maria:** Formal analysis. **C D Aju:** Conceptualization, Methodology, Review & editing. **A. L. Achu:** Review & editing.

Declaration of competing interest

The authors declare that they have no known financial or personal conflicts of interest that could have influenced the work reported in this paper.

Acknowledgements

The first and second authors thank the Executive Director of the Centre for Water Resources Development and Management (CWRDM) for providing facilities to carry out the research at Hydrology and Climatology Research Group HCRG of CWRDM. The authors also thank the Central Ground Water Board (CGWB) Thiruvananthapuram for the secondary groundwater data used for this research.

References

Abdulhussein, F.M. Hydrochemical Assessment of Groundwater of Dibdibba Aquifer in Al-Zubair Area, Basra, South of Iraq and Its Suitability for IrrigationPurposes. Iraqi J. Sci. 2018, 59, 135–143.

Adimalla, N. 2018 Groundwater quality for drinking and irrigation purposes and potential health risks assessment: a case study from semiarid region of South India. Exposure and Health Journal 11, 109–123.

Adimalla, N., Dhakate, R., Kasarla, A., Taloor, A.K., 2020. Appraisal of groundwater quality for drinking and irrigation purposes in Central Telangana, India. Groundwater for Sustainable Development 10 (126), 100334. DOI:10.1016/j.gsd.2020.100334.

Ahmed AN, Othman FB, Afan HA, Ibrahim RK, Fai CM, Hossain MS, Ehteram M (2019) Machine learning methods for better water quality prediction. J Hydrol 578:124084. DOI:10. 1016/j.jhydr ol. 2019. 124084

Akter T, Jhohura FT, Akter F, Chowdhury TR, Mistry SK, Dey D, Barua MK, Islam MA, Rahman M (2016) Water Quality Index for measuring drinking water quality in rural Bangladesh: a crosssectional study. J Heal Popul Nutr 35:1–12. DOI:10. 1186/ s41043-016- 0041-5

Al-Hadithi M, Hasan K, Algburi A, Al-Paruany K (2019) Groundwater quality assessment using irrigation water quality index and GIS in Baghdad, Iraq. JJEES 10(1):15–20

Aliyu, T., Balogun, O., Namani, C., Olatinwo, L. & Aliyu, A. 2017 Assessment of the presence of metals and quality of water used for irrigation in Kwara State, Nigeria. Pollution Journal 3 (3), 461–470.

Alogayell, H.M.; EL-Bana, E.M.M.; Abdelfattah, M. Groundwater Quality and Suitability Assessment for Irrigation Using Hydrogeochemical Characteristics and Pollution Indices: A Case Study of North Al-Quwayiyah Governorate, Central Saudi Arabia. Water 2023, 15, 3321. DOI:10.3390/w15183321

Alrajhi, A., Beecham, S., Bolan, N.S., Hassanli, A., 2015. Evaluation of soil chemical properties irrigated with recycled wastewater under partial root-zone drying irrigation for sustainable tomato production. Agric. Water Manag. 161, 127–135. DOI:10.1016/j.agwat.2015.07.013.

Amrani, S.; Hinaje, S.; El Fartati, M.; Gharmane, Y.; Yaagoub, D. Assessment of Groundwater Quality for Drinking and Irrigation in the Timahdite–Almis Guigou Area (Middle Atlas, Morocco). Appl. Water Sci. 2022, 12, 82.

Amiri V, Rezaei M, Sohrabi N (2014) Groundwater quality assessment using entropy weightedWater Quality Index (EWQI) in Lenjanat, Iran. Environ Earth Sci 72:3479–3490. DOI:10. 1007/s12665- 014- 3255-0

Ayers R, Westcott D (1985) Water quality for agriculture. 29. Food and Agriculture Organization of the United Nations, Rome

Azzirgue M, Cherif Kh, Tchakoucht TA, El Azhari H, Salmoun F (2022) Testing groundwater quality in Jouamaa Hakama Region (north of Morocco) using water quality indices (WQIs) and fuzzy logic method: an exploratory study. Water 14:3028. DOI:10. 3390/ w1419 3028

Batarseh M, Imreizeeq E, Tilev S, Al Alaween M, Suleiman W, Al Remeithi AM, Al Tamimi MK, Al Alawneh M (2021) Dataset for the physio-chemical parameters of groundwater in the Emirate of Abu Dhabi, UAE. Data Brief 38:107353. DOI:10. 1016/j. dib. 2021. 107353

Bui DT, Khosravi K, Tiefenbacher J et al (2020) Improving prediction of water quality indices using novel hybrid machine-learning algorithms. Sci Total Environ. DOI:10. 1016/j. scito tenv. 2020. 137612

Çadraku HS (2021) Groundwater quality assessment for irrigation: Case study in the Blinaja river basin, Kosovo. Civil Eng J 7(9):1515–1528. DOI:10. 28991/ cej- 2021- 03091 740

Chidambaram, S.; Anandhan, P.; Prasanna, M.V.; Thivya, C.; Thilagavathi, R.; Sarathidasan, J. Hydrochemistry of Groundwater in a Coastal Region and Its Repercussion on Quality, a Case Study—Thoothukudi District, Tamil Nadu, India. Arab. J. Geosci. 2014, 7, 939–950.

Chidambaram S, Prasanna MV, Nepolian M, Pradeep K, Banajarani P, Thivya C, Thilagavathi R (2022) Groundwater quality assessment for irrigation by adopting new suitability plot and spatial analysis based on fuzzy logic technique. Environ Res 204:111729. DOI:10. 1016/j. envres. 2021. 111729

Chowdury MSU, Emran T, Bin GS, Pathak A, Alam MM, Absar N, Andersson K, Hossain MS (2019) IoT based real-time river water quality monitoring system. Proced Comput Sci 155:161–168

Das A, Das SS, Chowdhury NR, Joardar M, Ghosh B, Roychowdhury T (2020) Quality and health risk evaluation for groundwater in Nadia district, West Bengal: an approach on its suitability for drinking and domestic purpose. Groundw Sustain Dev 10:100351

Docheshmeh Gorgij A, Wu J, Asghari Moghadam A (2019) Groundwater quality ranking using the improved entropy TOPSIS method: a case study in Azarshahr plain aquifer, east Azerbaijan Iran. Hum Ecol Risk Assess 25(1–2):176–190. DOI:10. 1080/ 10807 039. 2018. 15642 35

Docheshmeh Gorgij A, Askari Gh, Taghipour AA, Jami M, Mirfardi M (2023) Spatiotemporal forecasting of the groundwater quality for irrigation purposes, using deep learning method: long short-term memory (LSTM). Agri Water Manag 227:108088. DOI:10. 1016/j. agwat. 2022. 108088

Domenico, P.A. and Schwartz, F. W. (1990). Physical and Chemical Hydrogeology. John Wiley and Sons, New York, 824 p.

Doneen, L.D. Notes on Water Quality in Agriculture, Water Science and Engineering Paper 4001; Department of Water Science and Engineering, University of California: Davis, CA, USA, 1964.

Edmunds, W. M., Shanda, P., Hartb, P. & Warde, R. S. 2003 The natural (baseline) quality of groundwater: a UK pilot study. Science of the Total Environment 310, 25–35.

El Maghraby, M., Bamousa, A.O., 2021. Evaluation of groundwater quality for drinking and irrigation purposes using physicochemical parameters at Salilah area, Madinah Munawarah District, Saudi Arabia. J. Taibah Univ. Sci. 15 (1), 695–709. DOI:10.1080/16583655.2021.1996112.

El Mountassir O, Bahir M, Ouazar D, Ouhamdouch S, Chehbouni A, Ouarani M (2020) The use of GIS and water quality index to assess groundwater quality of krimat aquifer (Essaouira; Morocco). SN Appl Sci.

DOI:10. 1007/ s42452- 020- 2653z

Fallatah, O.; Khattab, M.R. Evaluation of Groundwater Quality and Suitability for Irrigation Purposes and Human Consumption in Saudi Arabia. Water 2023, 15, 2352.

FAO. Water for Sustainable Food and Agriculture: A Report Produced for the G20 Presidency of Germany; FAO: Rome, Italy, 2017.

Gao Y, Qian H, Ren W, Wang H, Liu F, Yang F (2020) Hydrogeochemical characterization and quality assessment of groundwater based on integrated-weight water quality index in a concentrated urban area. J Clean Prod. DOI:10. 1016/j. jclep ro. 2020. 121006

Guey-Shin Sh, Bai-You Ch, Chi-Ting Ch, Pei-Hsuan Y, Tsun-Kuo Ch (2011) applying factor analysis combined with kriging and information entropy theory for mapping and evaluating the stability of groundwater quality variation in Taiwan. Int J Environ Res Public Health 8:1084–1109. DOI:10. 3390/ ijerp h8041 084

Haritash, A.K., Kaushik, C.P., Kaushik, A., Kansal, A., Yadav, A.K., 2008. Suitability assessment of groundwater for drinking, irrigation and industrial use in some North Indian villages. Environ. Monit. Assess. 145 (1), 397–406. DOI:10.1007/ s10661-007-0048 x.

Houemenou H, Tweed S, Dobigny G, Mama D, Alassane A, Silmer R, Babic M, Ruy S, Chaigneau A, Gauthier P, Socohou A, Dossou HJ, Badou S, Leblanc M (2020) Degradation of groundwater quality in expanding cities in West Africa. A case study of the unregulated shallow aquifer in Cotonou. J Hydrol 582:124438.
DOI:10. 1016/j. jhydr ol. 2019. 124438

Jahin HS, Abuzaid AS, Abdellatif AD (2020) Using multivariate analysis to develop irrigation water quality index for surface water in Kafr El-Sheikh Governorate, Egypt. Environ Technol Innov 17:100532.
DOI: 10. 1016/j. eti. 2019. 100532

Khan, I., Awan, S.A., Rizwan, M., Ali, S., Hassan, M.J., Brestic, M., Zhang, X., Huang, L., 2021.
Effects of silicon on heavy metal uptake at the soil-plant interphase: a review. Ecotoxicol. Environ. Saf. 222, 112510
DOI:10.1016/j.ecoenv.2021.112510.

Li P, Qian H, Wu JH (2010) Groundwater quality assessment based on improved Water Quality Index in Pengyang County, Ningxia North West China. E-J Chem 7:209–216

Li, P., Wu, J. & Qian, H. 2013 Assessment of groundwater quality for irrigation purposes and identifcation of hydrogeochemical evolution mechanisms in Pengyang County, China. Environmental Earth Sciences 69, 2211–2225.

Malakar, A., Snow, D. & Ray, C. 2019 Irrigation water quality-a contemporary perspective. Water Journal 11, 1482. DOI:10.3390/w11071482.

Meireles A, Andrade EM, Chaves L, Frischkorn H, Crisostomo LA (2010) A new proposal of the classification of irrigation water. Rev Cienc A Gron 41(3):349–357

Mirzavand, M., Ghasemieh, H., Sadatinejad, S. J. & Bagheri, R. 2020 An overview on source, mechanism and investigation approaches in groundwater salinization studies. International Journal of Environmental Sciences and Technology 17, 2463–2476.

Mukherji, A., 2007. The energy-irrigation nexus and its impact on groundwater markets in eastern Indo-Gangetic basin: evidence from West Bengal, India. Energy Pol. 35 (12), 6413–6430. DOI:10.1016/j.enpol.2007.08.019.

Mukhopadhyay, B.P., Chakraborty, A., Bera, A., Saha, R., 2022. Suitability assessment of groundwater quality for irrigational use in Sagardighi block, Murshidabad district, West Bengal. Appl. Water Sci. 12 (3), 1–17. DOI:10.1007/s13201-021-01565-4.

Passos ALL, Muniz DHF, Rangel LP, Oliveira-Filho EC (2019) Selection of variables in the definition of a water quality index for the Brazilian Federal District. Rev Ambiente Água 14:16. DOI:10. 4136/ ambi- agua. 2385

Rahman MM, Bodrud-Doza M, Siddique T, Zahid A, Islam A (2020) Spatiotemporal distribution of fluoride in drinking water and associated probabilistic human health risk appraisal in the coastal region Bangladesh. Sci Total Environ 724:138316.
DOI:10. 1016/j. scito tenv

Ramadan, E. M., Fahmy, M. R., Nosair, A. M. & Badr, A. M. 2019 Using geographic information system (GIS) modeling in evaluation of canals
water quality in Sharkia Governorate, East Nile Delta, Egypt. Modeling Earth and Systems
Environment 5, 1925–1939.

Ravikumar, P.; Venkatesharaju, K.; Prakash, K.L.; Somashekar, R.K. Geochemistry of Groundwater and Groundwater Prospects Evaluation, Anekal Taluk, Bangalore Urban District, Karnataka, India. Environ. Monit. Assess. 2011, 179, 93–112.

Rawat, K.S.; Singh, S.K.; Gautam, S.K. Assessment of Groundwater Quality for Irrigation Use: A Peninsular Case Study. Appl. Water Sci. 2018, 8, 233.

Richards LA (1954) Diagnosis and improvement of saline and alkali soils. United States Department of Agriculture, Washington DC

Sadashivaiah C, Ramakrishnaiah CR, Ranganna G. Hydrochemical analysis and evaluation of groundwater quality in Tumkur Taluk, Karnataka state, India. Int J Environ Res Public Health. 2008

Sep;5(3):158-64. DOI:10.3390/ijerph5030158. PMID: 19139534; PMCID: PMC3699986.

Safiur Rahman, M., Saha, N., Islam, A.R.M.T., Shen, S., Bodrud-Doza, M., 2017. Evaluation of water quality for sustainable agriculture in Bangladesh. Water Air Soil Pollut. 228 (10) https://doi.org/10.1007/s11270-017-3543-x.

Sarkar, S., Roy, A., Bhattacharjee, S., Shit, P.K., Bera, B., 2021. Effects of COVID-19 lockdown and unlock on health of Bhutan-India-Bangladesh trans-boundary rivers. Journal of Hazardous Materials Advances 4 (February 2022), 100030. DOI:10.1016/j.hazadv.2021.100030.

Shammi, M., Rahman, R., Rahman, M.M., Moniruzzaman, M., Bodrud-Doza, M., Karmakar, B., Uddin, M.K., 2016. Assessment of salinity hazard in existing water resources for irrigation and potentiality of conjunctive uses: a case report from Gopalganj District, Bangladesh. Sustainable Water Resources Management 2 (4), 369–378. DOI:10.1007/s40899-016-0064-5.

Siebert S, Burke J, Faures J-M, Frenken K, Hoogeveen J, Doll P, Portmann FT (2010) Groundwater use for irrigation – a global inventory. Hydrol Earth Syst Sci 14:1863–1880. DOI:10. 5194/ hessd-7- 3977- 2010

Simsek C, Gunduz O (2007) IWQ index: A GIS integrated technique to assess irrigation water quality. Environ Monitor Assess 128:277– 300. DOI:10. 1007/ s10661- 006- 9312-8

Singh S, Ghosh NC, Gurjar S, Krishan G, Kumar S, Berwal P (2018) Index-based assessment of suitability of water quality for irrigation purpose under Indian conditions. Environ Monit Assess 190:190. DOI:10. 1007/ s10661- 017- 6407-3

Todd, D.K.; Mays, L.W. Groundwater Hydrology; John Wiley & Sons: Hoboken, NJ, USA, 2004; ISBN 0471059374.

Tumkur Taluk, Karnataka State, India. Int. J. Environ. Res. Public Health 2008, 5, 158–164.

Velasco-Muñoz, J., Aznar-Sánchez, J., Belmonte-Ureña, L. & Román-Sánchez, M. 2018 Sustainability water use in agriculture: a review of worldwide research. Sustainability Journal 10, 1084. DOI:10.3390/su10041084.

Valentini M, Dos Santos GB, Muller Vieira B (2021) Multiple linear regression analysis (MLR) applied for modeling a new WQI equation for monitoring the water quality of Mirim Lagoon, in the state of Rio Grande do Sul—Brazil. SN Appl Sci 3:1–11. DOI: 10. 1007/ s42452- 020- 04005-1

WHO. Guidelines for Drinking Water Quality, 4th ed.; WHO Press: Geneva, Switzerland, 2011.

Wu J, Zhang Y, Zhou H (2020) Groundwater chemistry and groundwater quality index incorporating health risk weighting in Dingbian County Ordos basin of northwest China. Chem Der Erde. DOI:10. 1016/j. chemer. 2020. 125607

Zafar, M.M., Sulaiman, M.A., Prabhakar, R. et al. Evaluation of the suitability of groundwater for irrigational purposes using irrigation water quality indices and geographical information systems (GIS) at Patna (Bihar), India. Int J Energ Water Res 8, 241–254 (2024). DOI:10.1007/s42108-022-00193-1

Zaman, M., Shabbir, A., Shahid, A. & Heng, L. 2018 Irrigation water quality. International Atomic Energy Agency. Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques 113–133. DOI:10.1007/978-3-319-96190-3_5.

Zhu JJ, Yu LZ, Xu TL, Wei X, Yang K (2019) Comparison of water quality in two catchments with different forest types in the headwater region of the Hun River, Northeast China. J Res 30:565–576. DOI:10. 1007/ s11676- 018- 0688-4